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The Effect of Stabilization Treatments on Disk Alloy CH98

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THE EFFECT OF STABILIZATION TREATMENTS ON DISK ALLOY CH98

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INTRODUCTION

Gas turbine engines for future subsonic transports will probably have higher pressure ratios which will require nickel-base superalloy disks with 1300F to 1400F temperature capability. Several advanced disk alloys are being developed to fill this need. One of these, CH98, is a promising candidate for gas turbine engines and is being studied in NASA's AST Program. For large disks, residual stresses generated during quenching from solution heat treatments are often reduced by a stabilization heat treatment, in which the disk is heated to 1500 or 1600F for several hours followed by a static air cool. The reduction in residual stress levels lessens distortion during machining of disks. However, previous work on CH98 has indicated that stabilization treatments can also decrease creep capability (Ref. 1). In this study, a systematic variation of stabilization temperature and time was investigated to determine its effect on 1300F tensile and, more importantly, creep behavior. Dwell crack growth rates were also measured for selected stabilization conditions. As these advanced disk alloys may be given a supersolvus solution or a subsolvus solution heat treatment for a given application, it was decided that both options would be studied.

MATERIAL & TEST PROCEDURE

CH98 is a nickel-base superalloy, with a total gamma prime content of about 60%. The composition of CH98 is shown in Table 1. All material in this study was produced from a single batch of argon atomized powder which was consolidated by hot compaction at 1925F followed by extrusion at 1965F with an 8:1 reduction ratio. Specimen blanks were cut from the extrusions and half of the blanks were HIPed at 2200F/30KSI/3HR to achieve a coarse grain size, while the other half were HIPed at 2100F/30KSI/3HR to achieve a fine grain size. After HIPing, the blanks with the coarse grain microstructure were solutioned at 2200F while the blanks with the fine grain microstructure were solutioned at 2100F for 1 hour in a vacuum furnace. They were subsequently quenched to achieve an initial cooling rate of 150F/MIN to simulate production conditions. At this point the blanks were separated into six lots, A through F, and given a different stabilization treatment as defined in Table 2. Note that lot A received no stabilization treatment, while lots B through F were stabilized using a variety of times and temperatures, such that B, D, and F received increasing stabilization temperature at 2HR while C, D, and E received increasing stabilization time at 1550F. All lots were subsequently aged at 1400F for 8HR.

Tensile, creep and crack growth specimens were machined from the heat treated blanks. The tensile and creep specimens were identical with a cylindrical gage section measuring 0.160" in diameter by 0.750" long. Tensile tests were run at 1300F at a strain rate of 0.5%/minute through yield. Creep tests were run at 1300F and 90KSI. Crack growth rates were measured using a K_B Bar test developed by Vanstone (Ref. 2). The K_B Bar had a rectangular cross section measuring 0.40" wide and 0.17" thick with a thin, semicircular surface flaw 0.015" in diameter located at the center of the 0.40" face. A precrack extending to a depth of about 0.030" (0.015" notch plus 0.015" crack) was introduced by high frequency cycling at room temperature before dwell testing at 1300F. The peak cyclic stress for precracking and testing was held constant throughout at a stress level of about 100KSI. A tension-tension dwell cycle was employed during testing at 1300F with a 180 second dwell at peak stress and an R-ratio of 0.1. Dwell crack growth rates were monitored using a DC potential drop technique from a K_{MAX} of 20 to 40KSI-IN$^{0.5}$ with two distinct calibration points per test. While tensile and creep tests were run on all lots, crack growth tests were only run on lot A, no stabilization, and lot D, the midpoint for stabilization time and temperature.

General microstructural characterization of all lots were performed via scanning electron microscopy (SEM), while detailed microstructural analyses of lots A and D were also performed via transmission electron microscope (TEM).

RESULTS

The microstructural characterization of lots A through F showed the grain size of subsolvus solutioned material, 21 series, to be ASTM 11 to 12 and supersolvus solutioned material, 22 series, to be ASTM 7 to 8, Table 3. As one might expect, the subsolvus solutioned material also contains a significant amount of primary gamma prime which is absent in the supersolvus solutioned material. The cooling gamma prime was also larger for supersolvus solutioned material. Unlike solution treatments, stabilization treatments did not have a significant impact on the size of the cooling gamma prime. Figure 1 shows the cooling gamma prime sizes for lot A, no stabilization, and lot F, the most severe stabilization treatment, are essentially equivalent. Changes in carbide content and size of fine gamma prime precipitates were evaluated with TEM. As previously stated only lots A and D were studied. Stabilization increased the frequency of $M_{23}C_6$ carbides at grain boundaries as seen in Figure 2a. Quantitative analysis indicated the fine gamma prime within the grains has coarsened, as seen in Figure 3. Stabilization also appears to have sporadically coarsened the gamma prime at grain boundaries, Figure 2b.

The 1300F tensile data are summarized in Table 4. The most significant variation was seen in yield strength. Grain size differences show the most pronounced effect with the coarse grain material, 22 series, averaging about 131KSI and the fine grain material, 21 series, averaging about 142KSI. It also appeared that increasing stabilization time and temperature tended to decrease yield strength, although this effect was much less pronounced than the grain size effect. Unlike yield strength, tensile strength showed little variation. The tensile strength of all variants fell between 170 and 174KSI, and did not appear to show any systematic trend . The ductility of all variants of CH98 was quite good, being greater than 20% elongation and 25% reduction in area for all cases, although the coarse grain material, 22 series, did tend to have higher values.

Creep data on CH98 generated at 1300F/90KSI is summarized in Table 5. In most cases duplicate tests were run to about 0.5% and one of the tests from each lot and series was run to failure. The time to 0.2% creep, an important design consideration for disk operation, is presented graphically in Figure 4. From this data it is obvious that all of the single step stabilization treatments studied here had a significant impact on 0.2% creep. It would appear that increasing stabilization time or temperature decreased the time to 0.2% creep over the range of data studied. Further, the fine grain material appeared to be more sensitive to the effects of stabilization. Rupture lives were also affected by stabilization, Figure 5. As with 0.2% creep, stabilization treatments were found to debit rupture life, with the fine grain material showing the greatest decrease. Rupture ductility did not, however, seem to be affected by stabilization treatment. Coarse grain material, 22 series, had an elongation of 16%, while the elongation of the fine grain material, 21 series, was about 10%.

The 1300F dwell crack growth rates of lot A specimens with no stabilization, and lot D specimens with a 1550F/2HR stabilization are compared in Figure 6 for each grain size. It is clear that stabilization has decreased the rate of crack growth for either grain size. As shown in other studies (Ref. 1 & 3), the finer grain size produces a faster rate of crack growth for stabilized material as well as unstabilized material.

DISCUSSION

As previously stated, stabilization heat treatments altered the microstructure in two ways. First, it promoted $M_{23}C_6$ carbide formation at grain boundaries. Second, it also coarsened the fine gamma prime precipitates within the grains and appeared to promote sporadic coarsening of gamma prime precipitates at grain boundaries.

The effect of these microstructural changes on tensile, creep, and crack growth are now examined. The decrease in yield strength attributed to stabilization was most likely associated with the coarsening of gamma prime throughout the microstructure. However, the impact of stabilization heat treatments on creep could be tied to microstructural changes at grain boundaries or coarsening of the fine gamma prime. A previous study (Ref. 1) has shown that additions of tungsten and niobium suppress the deleterious impact of stabilization on creep. As these alloying additions are more likely to affect the coarsening rate of gamma prime than alter carbide precipitation at grain boundaries, one could conclude that coarsening of the fine gamma prime is largely responsible for decreasing the creep resistance of CH98 after stabilization. For dwell crack growth, the importance of microstructural changes at grain boundaries is probably more influential, as the fracture path was intergranular in all cases. However, it was not possible to separate the relative effects of carbides and grain boundary gamma prime precipitates on crack growth.

SUMMARY & CONCLUSIONS

Stabilization heat treatments were found to affect the 1300F tensile, creep, and dwell crack growth rates of an advanced nickel-base disk alloy, CH98. The 0.2% creep time showed a significant decrease with stabilization which was accentuated when the stabilization temperature increased (1500F to 1600F) or the stabilization time increased (1HR to 4HR). Yield strength also decreased when CH98 was given a stabilization treatment, although tensile strength was relatively constant. Unlike creep and tensile properties, dwell crack growth resistance was improved by stabilization.

Large disks often require a stabilization heat treatment to minimize distortion during machining. Therefore, the choice of CH98 as an alloy for large disks is certainly handicapped by a significant reduction in creep properties after stabilization. For small disks where distortion is less of a problem, direct age CH98 (no stabilization) does possess an attractive set of properties which can be utilized in advanced turbine engines of smaller regional aircraft.

REFERENCES

1. Gayda, J., The Effect of Tungsten and Niobium Additions on Disk Alloy CH98, AST 016, NASA Report, August 1997.

2. Vanstone, R. H. and Richardson, T. L., Potential-Drop Monitoring of Cracks in Surface-Flawed Specimens, Automated Test Methods for Fracture and Fatigue Crack Growth, ASTM STP 877, 1985, pp. 148-166.

3. Gayda, J., Alloy 10: A 1300F Disk Alloy, AST 013, NASA Report, June 1997.

Table 1. Alloy Composition (W/O)									
Co	Cr	Al	Ti	Mo	Ta	C	B	Zr	Ni
17.90	11.60	3.90	4.00	2.90	2.90	0.049	0.030	0.050	BAL

Table 2. Stabilization Treatment		
LOT	TEMPERATURE (F)	TIME (HR)
A	NONE	NONE
B	1500	2
C	1550	1
D	1550	2
E	1550	4
F	1600	2

Table 3. Grain Size		
SERIES/LOT	ASTM GRAIN SIZE	DEVIATION
21A	11.60	0.1
21B	11.60	0.1
21C	11.60	0.1
21D	11.70	0.1
21E	11.60	0.1
21F	11.80	0.1
22A	8.00	0.1
22B	7.40	0.3
22C	7.90	0.2
22D	7.10	0.1
22E	7.20	0.2
22F	7.00	0.2

Table 4. 1300F Tensile Properties

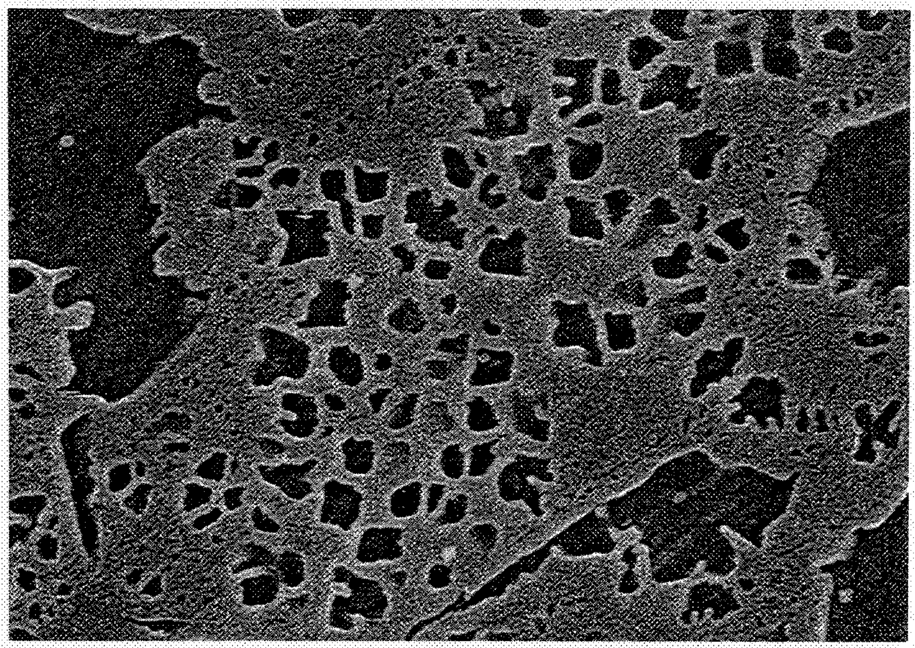
SERIES/LOT	0.2% YIELD	UTS	ELONGATION	RED. in AREA
	KSI	KSI	%	%
21A	142.6	171.1	19.5	26.2
21B	142.5	174.3	25.6	33.2
21C	141.0	172.9	23.4	31.7
21D	141.2	173.2	20.5	26.2
21E	141.5	171.4	22.3	30.2
21F	140.8	173.1	20.2	27.7
22A	133.7	173.9	23.8	31.2
22B	131.2	173.9	30.1	40.6
22C	133.6	173.7	30.2	39.8
22D	129.4	169.7	30.3	44.3
22E	128.6	173.2	30.2	42.3
22F	127.3	171.1	29.8	41.9

Table 5. 1300F Creep Data

SPECIMEN	0.2% CREEP	0.4% CREEP	CREEP LIFE	ELONGATION
SERIES/LOT	HOURS	HOURS	HOURS	%
21A-1	527	644		
21A-2	321	531	938	11.8
21B-1	151	194		
21B-2	146	201	555	9.3
21C-1	102	133		
21C-2	97	135	478	12.1
21D-2	45	72	323	10.7
21E-1	39	59	258	8.5
21E-2	40	60		
21F-1	40	58	217	7.7
21F-2	35	54		
22A-1	302	415	1614	16.1
22A-2	270	333		
22B-1	147	237	1362	15.2
22B-2	146	248		
22C-1	135	231	1110	15.9
22C-2	198	268		
22D-1	168	234	1395	16.5
22D-2	107	183		
22E-1	85	155		
22E-2	85	146	1302	18.2
22F-2	94	158	1212	16.4

Figure 1a. SEM comparison of γ' distributions, subsolvus solution heat treatment.

21A: No stabilization



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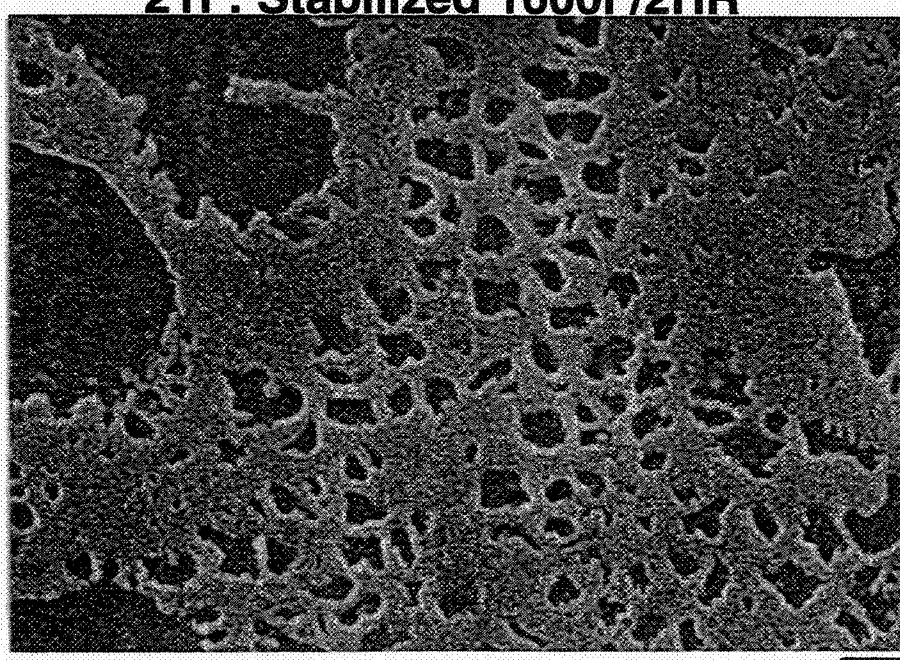
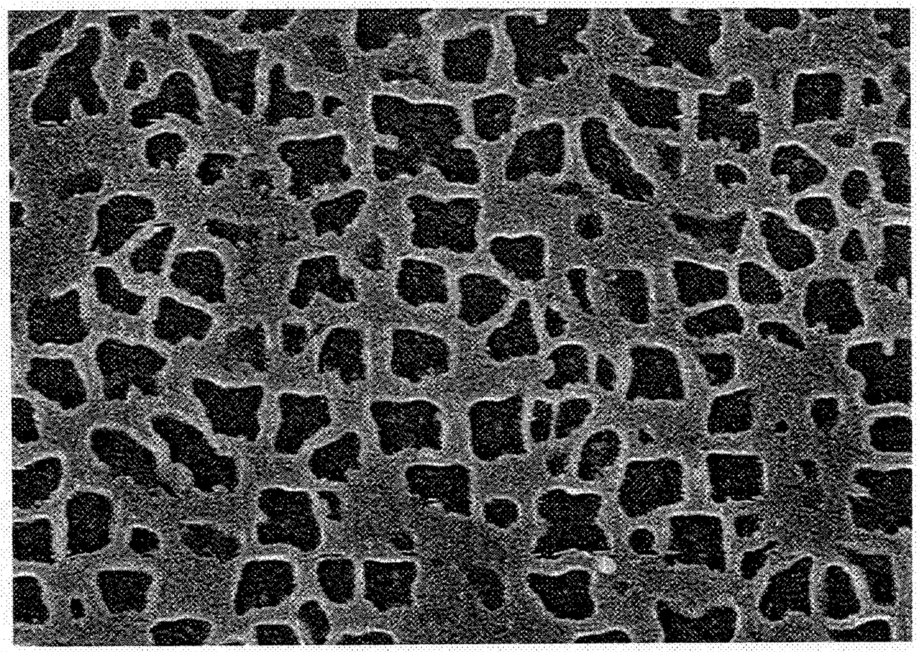
21F: Stabilized 1600F/2HR



0.5 µm

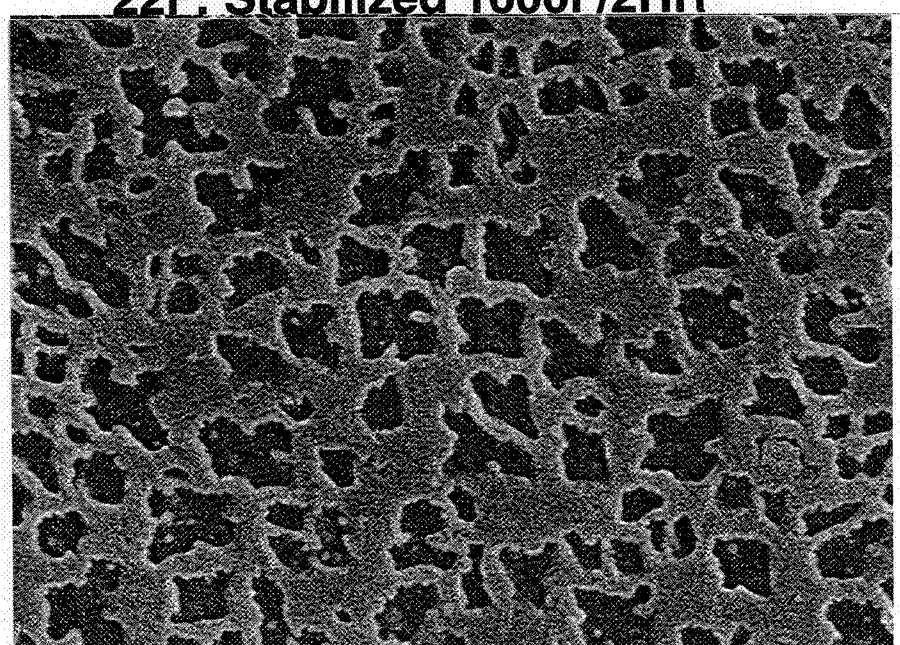
Figure 1b. SEM comparison of γ' distributions, supersolvus heat treatment.

22A: No stabilization



0.5 μm

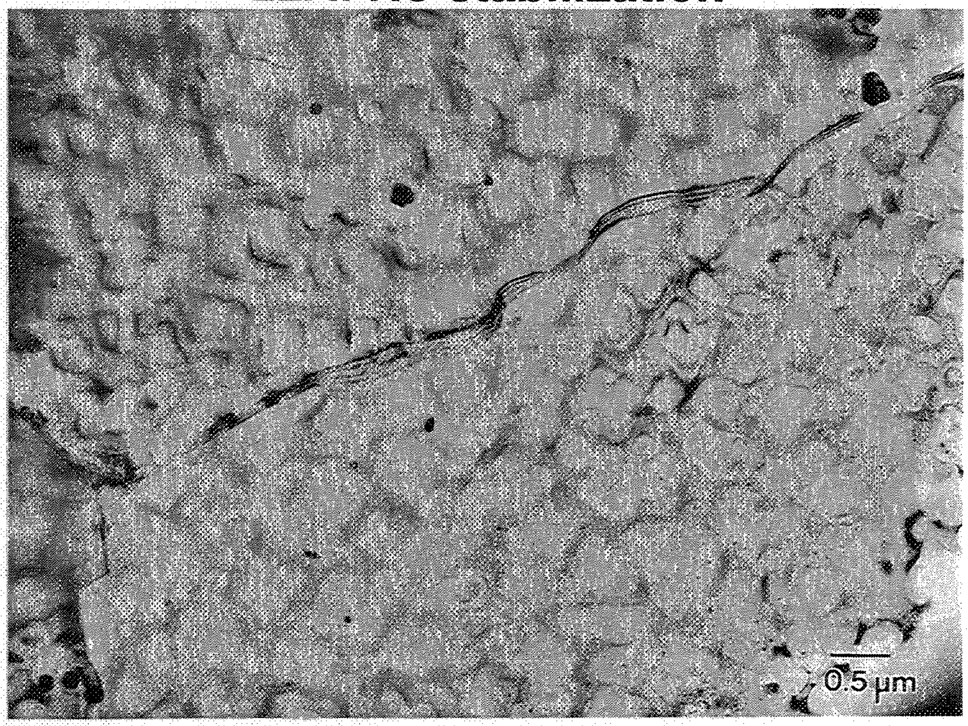
22F: Stabilized 1600F/2HR



0.5 μm

Figure 2a. Comparison of carbide distributions at grain boundaries.

22A: No stabilization



22D: Stabilized 1550F/2HR

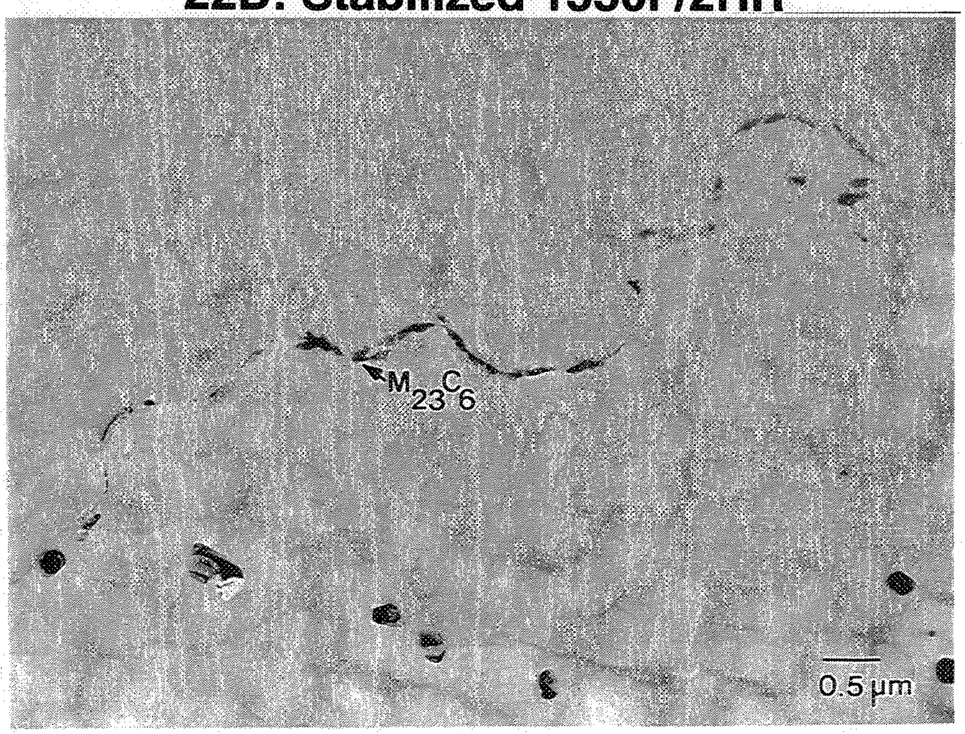
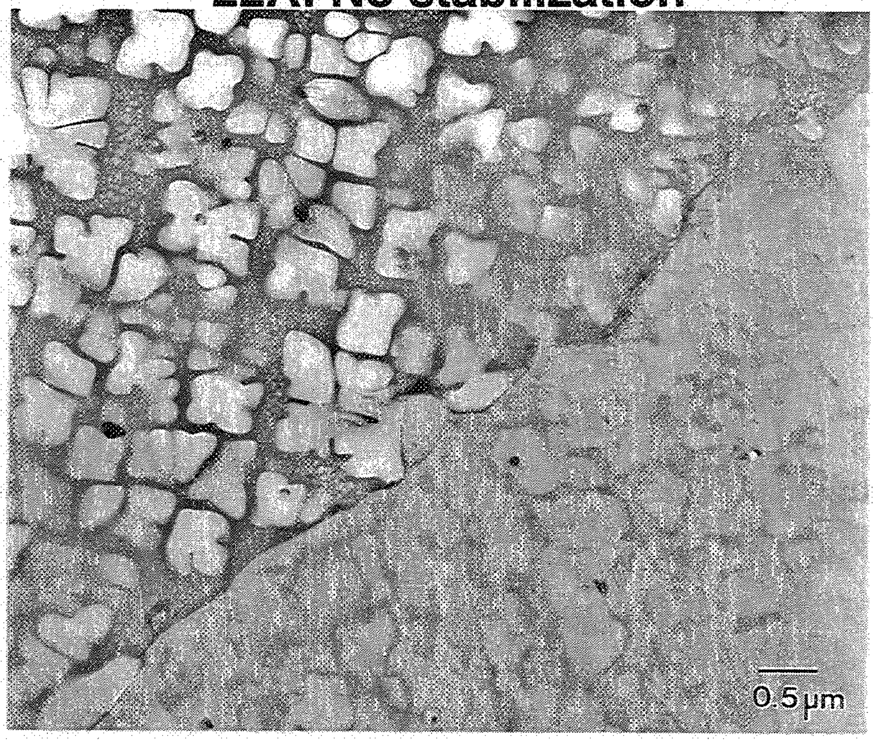


Figure 2b. Comparison of γ' distributions at grain boundaries.

22A: No stabilization



22D: Stabilized 1550F/2HR

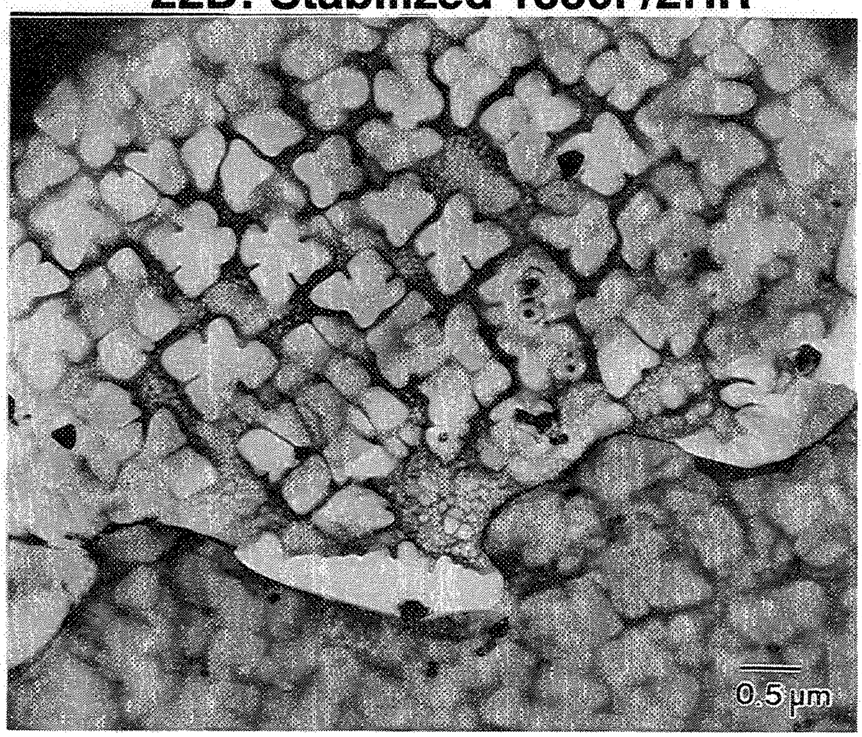


Figure 3. Fine gamma prime size distributions of CH98

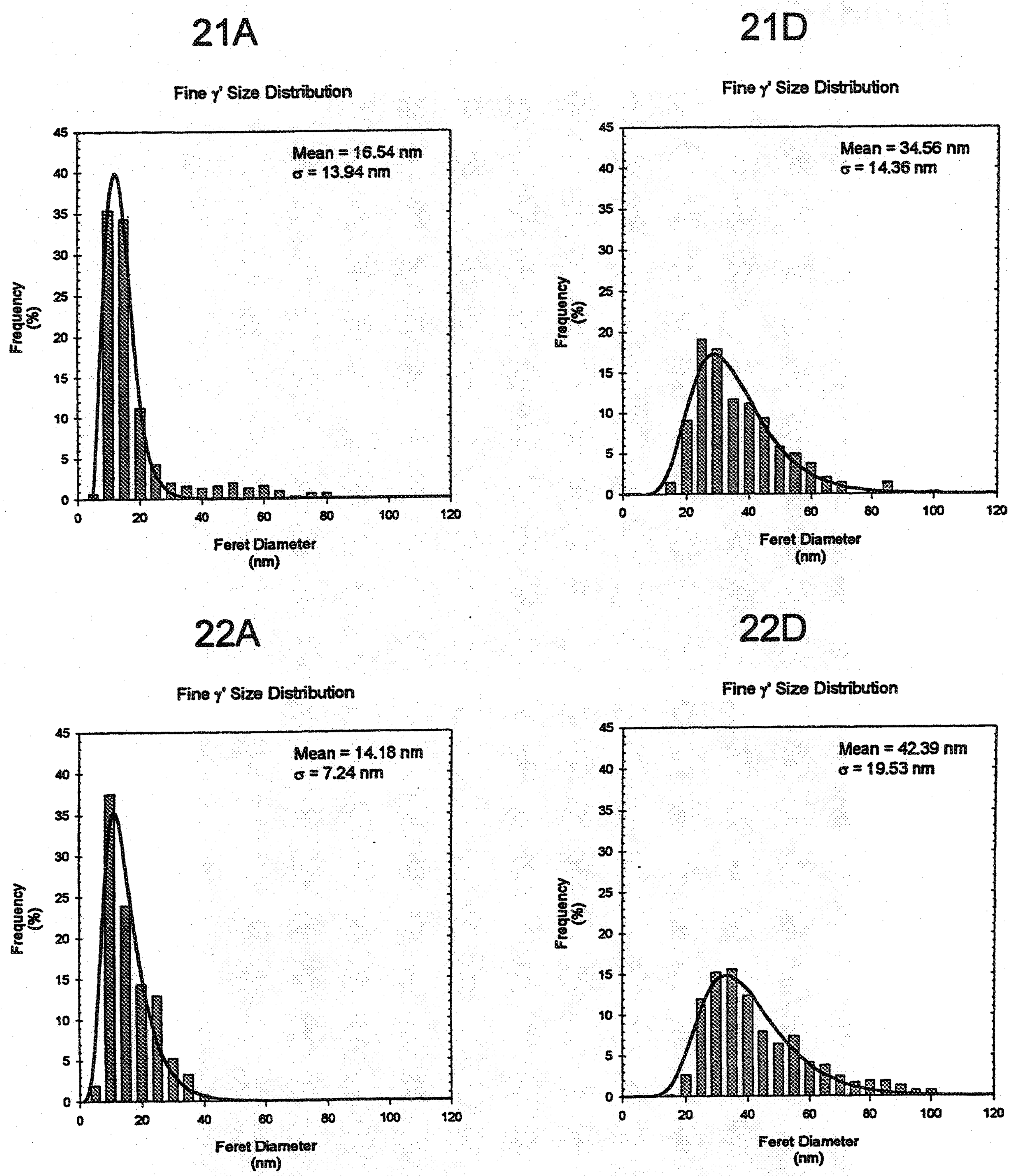


Figure 4. Creep data versus stabilization.

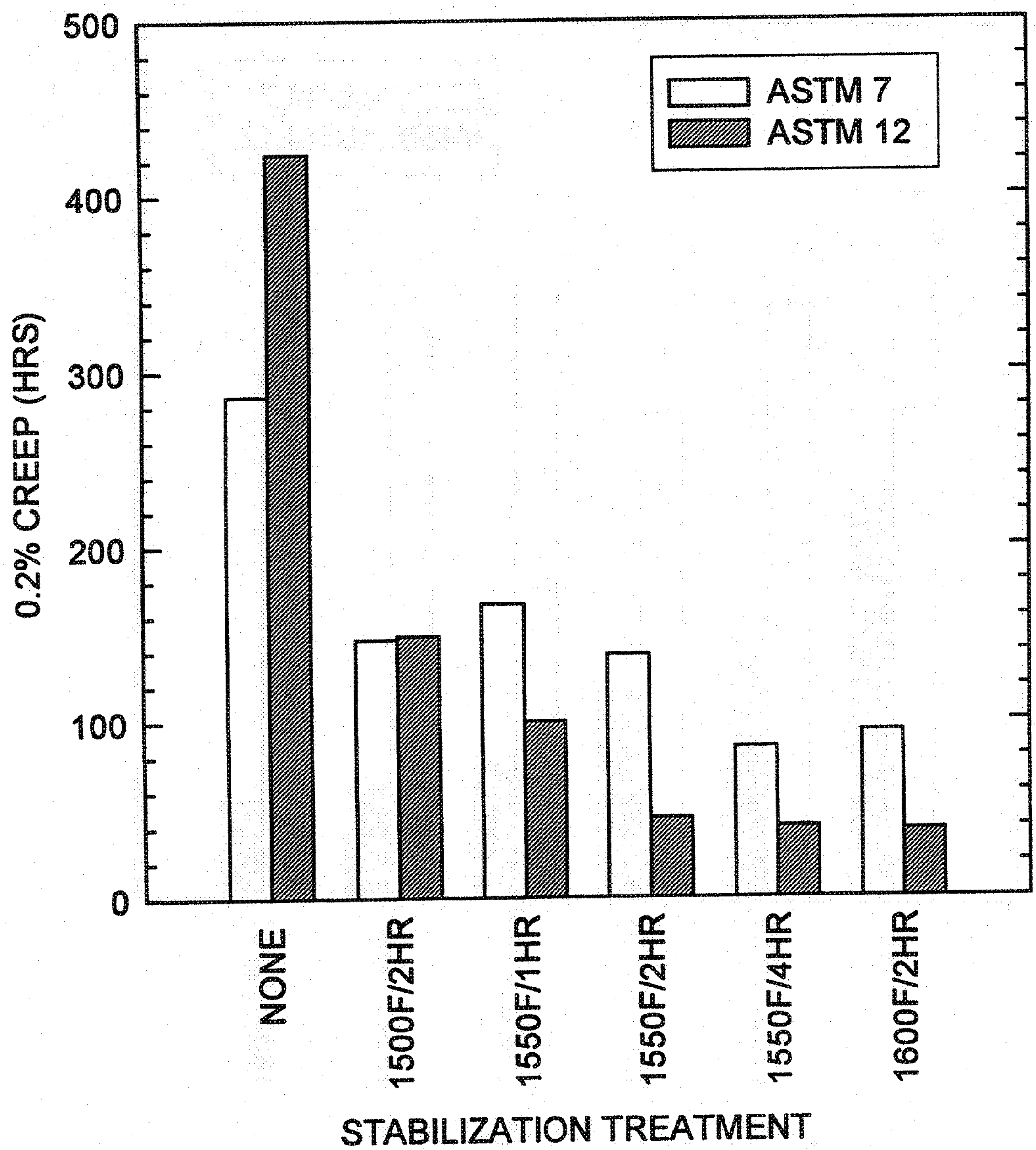


Figure 5. Creep life versus stabilization.

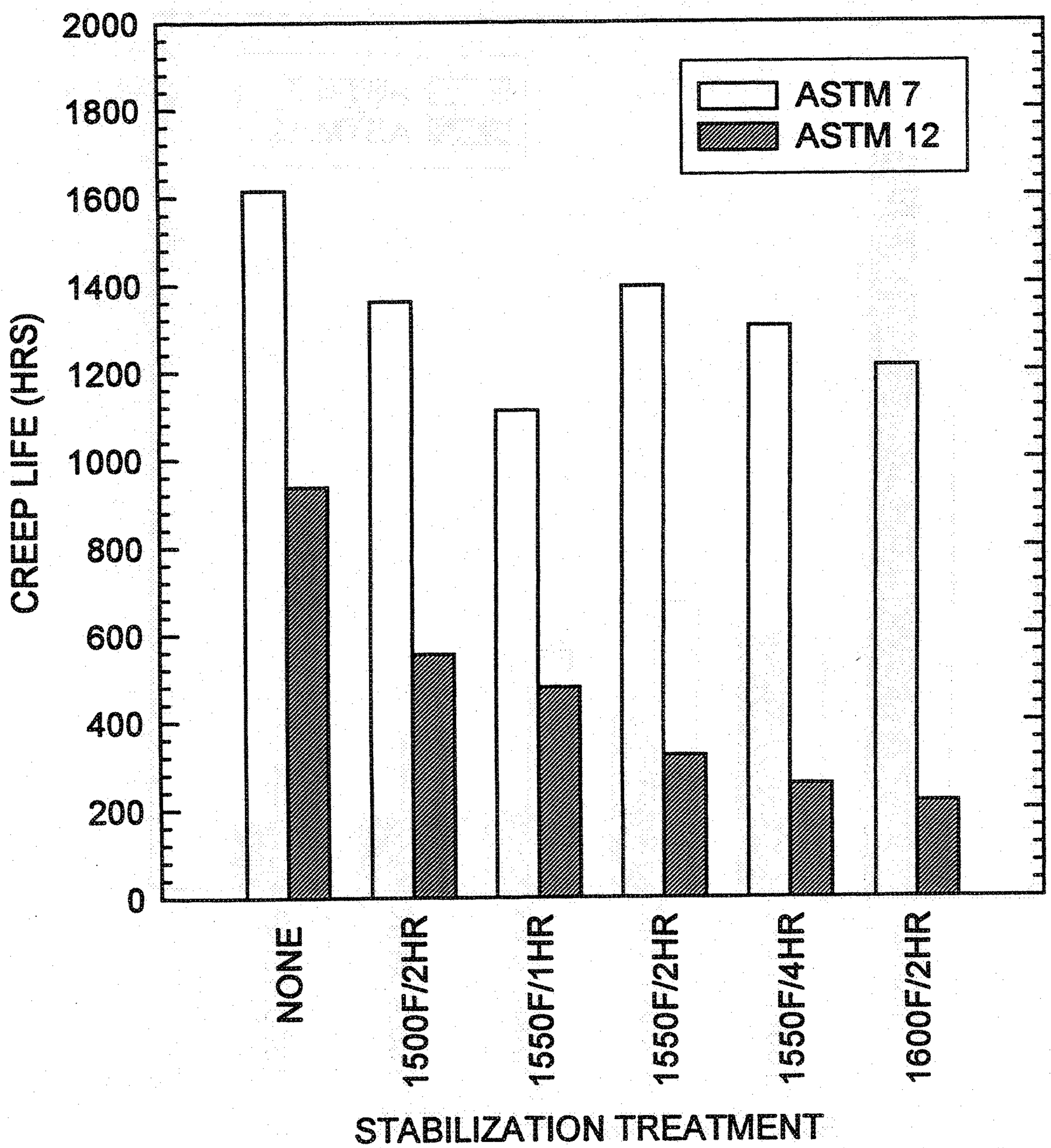
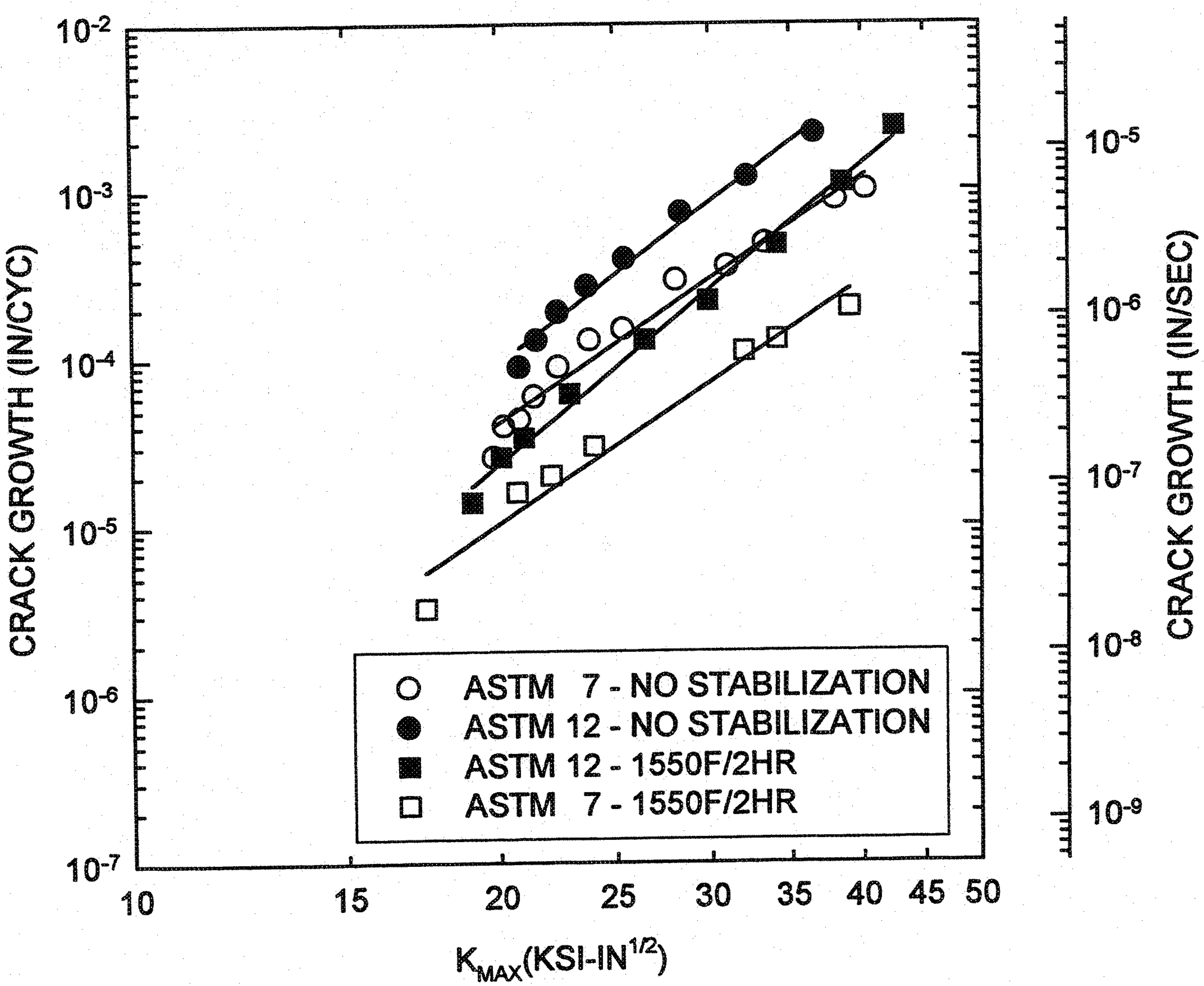


Figure 6. Dwell crack growth rates.



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13. ABSTRACT *(Maximum 200 words)*

Gas turbine engines for future subsonic transports will probably have higher pressure ratios which will require nickel-base superalloy disks with 1300 to 1400 ºF temperature capability. Several advanced disk alloys are being developed to fill this need. One of these, CH98, is a promising candidate for gas turbine engines and is being studied in NASA's Advanced Subsonic Technology (AST) program. For large disks, residual stresses generated during quenching from solution heat treatments are often reduced by a stabilization heat treatment, in which the disk is heated to 1500 or 1600 ºF for several hours followed by a static air cool. The reduction in residual stress levels lessens distortion during machining of disks. However, previous work on CH98 has indicated that stabilization treatments can also decrease creep capability. In this study, a systematic variation of stabilization temperature and time was investigated to determine its effect on 1300 ºF tensile and, more importantly, creep behavior. Dwell crack growth rates were also measured for selected stabilization conditions. As these advanced disk alloys may be given a supersolvus solution or a subsolvus solution heat treatment for a given application, it was decided that both options would be studied.

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